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Program Plan

National Aging Aircraft Research Program

SEPTEMBER 1991

U.S. Department of Transportation
Federal Aviation Administration
Technical Center
Atlantic City International Airport, New Jersey 08405

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16. Abstract

The inevitable effects of aircraft aging are progressive increases in the probability of damage from fatigue and corrosion. The continued safe operation of the United States commercial fleet will depend on the ability to anticipate required adjustments in the inspection and maintenance activities to compensate for the "aging" process. Increasing numbers of aircraft are exceeding their economic design life--the age at which they have historically been retired from major airline service. Presumably, commercial aircraft are designed for "infinite life with proper maintenance." But public confidence in operators' abilities to properly maintain older aircraft significantly diminished following the widely publicized failure of the Aloha Airlines 737 fuselage in 1988.

The FAA established the National Aging Aircraft Research Program (NAARP) to address this diminished public confidence in the airlines' ability to properly maintain their older aircraft. The goal of this program is to assure continued airworthiness of the United States commercial fleet of in-service and future aircraft beyond their economic design life. This will be achieved through improvements in equipment, techniques, practices, and procedures in aircraft and engine design, repair, maintenance, and inspection. The FAA will identify and direct the research to reach this goal. The results of the program will include a technical information data base that will be used by the FAA and/or industry to update or develop new rules, standards, advisories, and facilities.

17. Key Words
Aging Aircraft, Fatigue/Fracture
Corrosion, Nondestructive Inspection
Flightloads, Maintenance, Repair
Human Factors, Failsafe, Safe Life
Damage Tolerance Assessment, Link-Up

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LIST OF ACRONYMS

A&P	Airframe and Power Plant
AAM	FAA - Aviation Medicine
AANWG	Aging Aircraft NDI Working Group
AATF	Airworthiness Assurance Task Force
AC	Advisory Circular
AD	Airworthiness Directive
AFS	FAA - Flight Standards Services
AIA	Aerospace Industry Association
AIR	FAA - Aircraft Certification Service
ASNT	American Society of Nondestructive Testing
ATA	Air Transport Association
AVR	FAA Regulation and Certification Office
AXD	FAA System Development Office
CASR	Center for Aviation Systems Reliability
CCD	Charge Coupled Device
DOD	Department of Defense
DOT	Department of Transportation
DDTC	Development, Demonstration and Training Center
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
GAMA	General Aviation Manufacturers Association
GAO	General Accounting Office
ISN	Intelligent Services Network
MIL-STD	Military Standard
MSD	Multi-Site Damage
NAARP	National Aging Aircraft Research Program
NADC	Naval Air Development Center
NASA	National Aeronautics and Space Administration
NDI	Nondestructive Inspection
NR	Neutron Radiography
NTIAC	Nondestructive Testing Information and Analysis Center
OJT	On-the-Job Training
POD	Probability of Detection
PMI	Principal Maintenance Inspectors
PPT	Proof Pressure Test
RAA	Regional Airline Association
SB	Service Bulletins
SDR	Service Difficulty Report
SID	Structural Inspection Document
SSID	Supplemental Structural Inspection Document
TBD	To Be Determined
TSC	Transportation Systems Center
USAF	United States Air Force
VGH	Velocity, G-load, and Height

EXECUTIVE SUMMARY

The FAA has identified four major symptoms of the aging process.

- Increased frequency of cracking in uniformly stressed areas, leading to multi-site damage that causes large cracks to form more rapidly than is acceptable from a damage tolerance and detection viewpoint.
- Increased frequency of cracking in isolated regions of the structure, coupled with a high probability of these cracks being undetected during periodic inspections.
- The interaction of fatigue and corrosion.
- The effects of repairs.

In response to the aging issue, the FAA convened an International Conference on Aging Airplanes in June 1988 followed by an International Symposium on a more specific topic of Structural Integrity of Aging Airplanes in March 1990. The conference goal was to focus on the procedures needed to ensure the continued airworthiness of today's aging commercial fleet. The consensus of the gathered experts was:

- Operators should perform maintenance and inspections with more diligence and thoroughness.
- The FAA should conduct research and development in technical areas associated with fatigue/multi-site cracking, nondestructive inspection, and human factors.

To further support the need for this research and development effort, Congress enacted the Aviation Safety Act (Public Law 100-591) on November 3, 1988. The Act states that the FAA should undertake the following tasks, among others:

- Develop the technologies and conduct data analyses to predict the effects of aircraft design, maintenance, testing, wear, and fatigue on the life of the aircraft.
- Develop methods of improving aircraft maintenance technology and practices, including nondestructive inspection of aircraft structures.

As a result of these concerns ensuing from the increasing age of the air carrier fleet, and due to the recent fatigue and corrosion related failures of air carrier aircraft, the FAA has developed this National Aging Aircraft Research Program to ensure that the structural integrity of high-time/high-cycle aircraft is properly maintained.

The FAA's National Aging Aircraft Research Program has a set of interrelated short and long term goals. The short term goal is to define the extent of the aging problem of the current transport fleet. To accomplish this goal, the program will focus on the identification and resolution of issues relating to fatigue/multi-site cracking, corrosion, NDI, and human factors. Surveys of the existing systems and procedures, used by the Government and industry, will be made. The survey effort will be followed by workshops and seminars to identify needed improvements. Current regulations and advisory documents will be reviewed and updated, if

necessary. Benefits of the short term program will be in the form of updated documentation for use by government personnel as well as industry personnel engaged in engineering, manufacturing, and maintenance.

The long term goal of the program is to focus on existing issues applicable to future aircraft. It will seek to identify the failure mechanisms involved in aircraft fatigue and to develop methodologies for their detection and prevention. New technologies for onboard monitoring, advanced nondestructive inspection, and inspector training will be investigated for possible implementation. Research will be aimed at developing a philosophy of structural life enhancement for new aircraft designs. The benefits of the long term program will be in the form of new technologies and advanced documentation.

The research program is designed to address the currently identified six critical areas of the aging aircraft problem.

FATIGUE/FRACTURE, the subject that deals with crack initiation and growth in aircraft structures.

CORROSION, the damage due to aggressive chemical environment and its relationship to fatigue life and damage tolerance.

FLIGHT LOADS, the research area which deals with the quantification of structural forms of pressurization, landing, and gust, which participate in the fatigue process.

NONDESTRUCTIVE INSPECTION (NDI), the research area that focuses on finding structural flaws in the aircraft.

HUMAN FACTORS, concerned with human performance, as it impacts on the use of NDI to detect structural flaws.

MAINTENANCE/REPAIR, the research area which is directed at improving the airworthiness of the aircraft structure.

To ensure proper response to FAA and industry needs, a program has been conceived to:

- Establish, schedule, fund, and monitor projects with other elements of government, industry, academia, and research institutions. Project vehicles may include contracts, interagency agreements, memoranda of understanding, etc.
- Correlate and coordinate interrelated projects and monitor their progress and products.
- Conduct workshops and conferences where relevant issues can be discussed and resolved.
- Disseminate information to the management, oversight, and advisory groups in the FAA as well as in industry to inform them of the status and progress.
- Modify program direction to reflect interim results and new requirements.

1. INTRODUCTION

The philosophy of commercial aircraft design has been based on the assumption that with proper maintenance the life of the aircraft is infinite. However, the confidence of the general public in the ability of the operator to properly maintain older aircraft was significantly diminished following the widely publicized failure of the Aloha Airlines 737 fuselage as shown in figure 1. The Aloha incident served to highlight the fact that a result of an aircraft's aging process is its increased susceptibility to damage from fatigue and corrosion. Thus, the continued safe operation of an aircraft may depend upon the operator's ability to make the needed adjustments to the inspection and maintenance activities in order to compensate for the aging process.

The FAA has identified four major symptoms of the aging process that are listed below and which must be accounted for in a proper maintenance schedule as follows:

- Increased frequency of cracking in uniformly stressed areas, leading to multi-site damage that causes large cracks to form more rapidly than is acceptable from a damage tolerance and detection viewpoint.
- Increased frequency of cracking in isolated regions of the structure, coupled with a high probability of these cracks being undetected during periodic inspections.
- The interaction of fatigue and corrosion.
- The effects of repairs.

Research is needed to gain understanding of each of the aforementioned degradation modes.

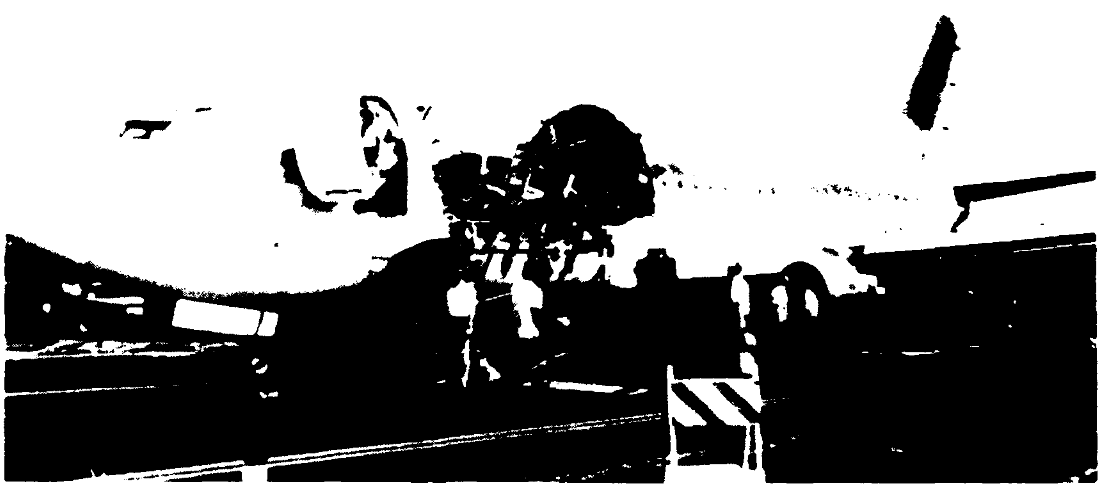


Figure 1. An extreme example of aging effect. This aircraft suffered an in-flight structural failure.

1.1 BACKGROUND

Since deregulation of the airline industry, the rapid growth of United States (U.S.) air carrier passenger traffic has been accompanied by the increased delivery times for new aircraft. The long lead time for the acquisition of new aircraft has thus forced the airlines to operate some of their aircraft beyond its original expected engineering life.

The average age of the U.S. commercial air carrier fleet has increased from 4.6 years in 1970 to 12.7 years in 1989. The historical and projected aging of the U.S. commercial air carrier fleet is illustrated in figures 2a and 2b. By early 1989, 31 percent of the U.S. commercial air carrier fleet was at least 20 years old, and nearly 800 more aircraft were rapidly approaching that age. In the past, 20-year-old aircraft were most often replaced by newer aircraft for airline service. However, this is no longer true, and by the turn of the century, 64 percent of the current fleet will be at least 20 years old. Although chronological age alone is not a direct measure of the structural integrity of an aircraft, it can alert operators to potential problems when age correlates with high numbers of flight hours and flight cycles.

In 1981, a Boeing 737-200 airplane suffered an in-flight breakup with the loss of over 100 lives. The aircraft, which entered service in May 1969, was owned by Far Eastern Air (Taiwan) and had 22,020 hours and 33,313 flight cycles. Investigations by the Government of Taiwan pointed to the corrosion-accelerated fatigue of fuselage skin panels as the probable cause of the breakup. On April 28, 1988, multiple fatigue cracks caused an Aloha Airlines Boeing 737-200 aircraft to lose part of its upper fuselage and resulted in the death of one flight attendant and injury to many passengers. The aircraft, which entered service in April 1969, had accumulated 35,496 hours and 89,690 flight cycles. While corrective repair action is being taken on 737 aircraft, the FAA also found that fatigue cracking could not be reliably detected by current visual or other nondestructive inspection (NDI) techniques.

In response to the aging issue, the FAA convened an International Conference on Aging Airplanes in June 1988, followed by an International Symposium on a more specific topic of Structural Integrity of Aging Airplanes, in March 1990, in Atlanta. The goal of the conference was to focus on the procedures needed to ensure the continued airworthiness of today's aging commercial fleet. The consensus of the gathered experts was the following:

- Operators should perform maintenance and inspections with more diligence and thoroughness.

- The FAA should conduct research and development in technical areas associated with fatigue/multi-site cracking, NDI, and human factors.

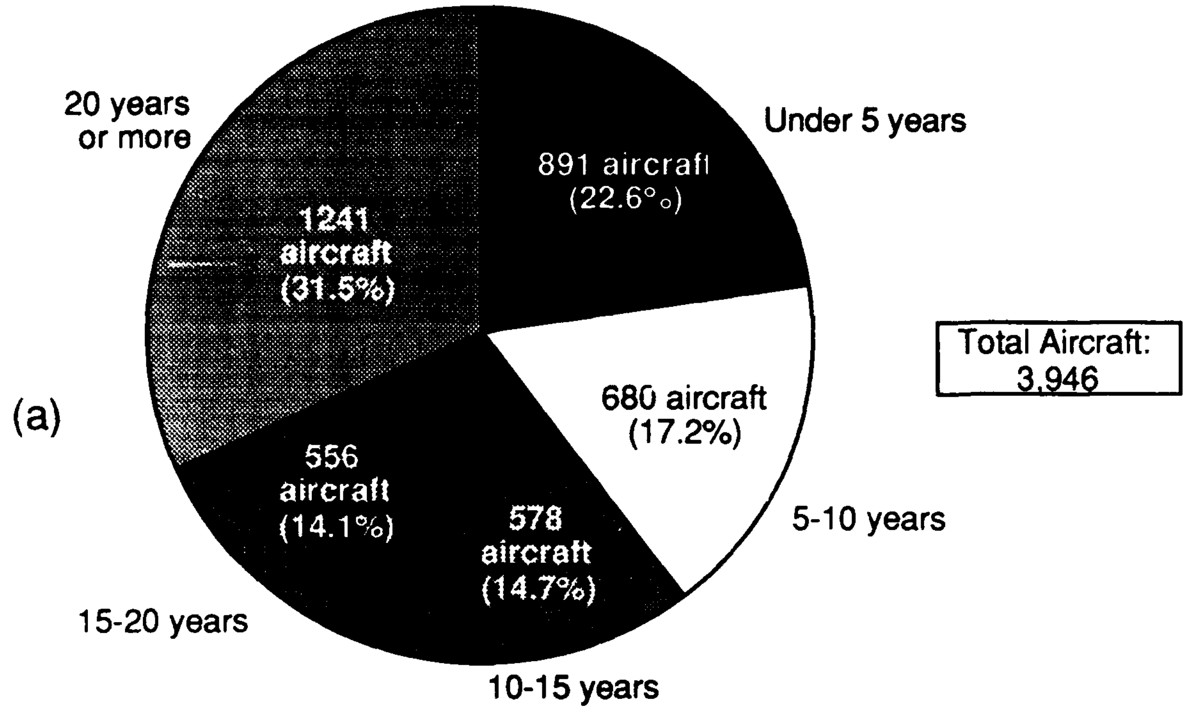
To further support the need for this research and development effort, Congress enacted the Aviation Safety Act (Public Law 100-591) on November 3, 1988. The Act states that the FAA will undertake the following actions:

- Develop the technologies and conduct data analyses to predict the effects of aircraft design, maintenance, testing, wear, and fatigue on the life of the aircraft.

- Develop methods of improving aircraft maintenance technology and practices, including NDI of aircraft structures.

As a result of all of these concerns ensuing from the increasing age of the air carrier fleet and due to the recent fatigue and corrosion related failures of air carrier aircraft, the FAA has

developed this National Aging Aircraft Research Program to ensure that the structural integrity of high time aircraft is properly maintained.



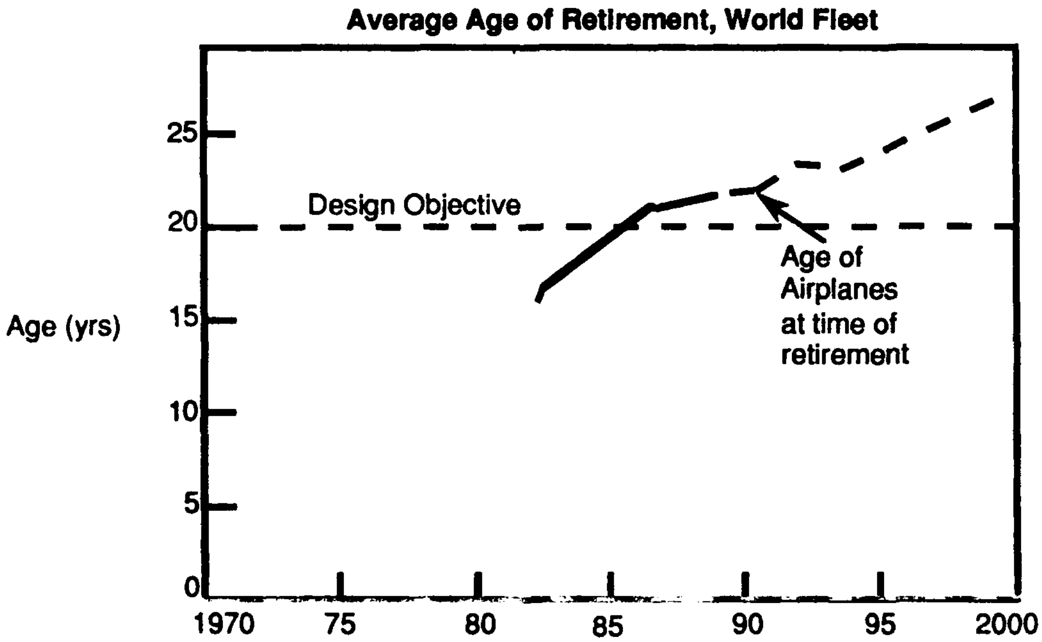


Figure 2. (a) U.S. commercial transport fleet age breakdown.
(b) World fleet average and retirement age histories.

1.2 DESIGN AND INSPECTION FOR SAFETY

Prior to 1978, the FAA required that transport aircraft structures certified under Federal Aviation Regulations (FAR) Part 25 be designed according to failsafe concepts. Failsafe requires sufficient structural redundancy be available that if a major structural element fails, the surrounding structure can safely carry the load. Also prior to 1978, some commuter aircraft structures certificated under FAR Part 23 were designed according to safe life concepts. Safe life specifies that the structure is unacceptable if existing NDI techniques can detect the presence of any cracks.

In 1978, the transport aircraft regulation was changed to a damage tolerance philosophy. Damage tolerance design requires that the structure has sufficient strength to fly safely, even with obviously detectable flaws. Scheduled inspections must detect the minor defects and damage before they can grow to a size which creates a safety problem.

Damage tolerance philosophy recognizes the fact that undetected damage can affect the adjacent structure. As damage spreads, it can destroy structural redundancy and this must be prevented by reliable inspections. The FAA strengthened the maintenance and inspection procedures for large pre-1978 transport aircraft, designed according to the failsafe philosophy, by its 1981 promulgation of Advisory Circular 91-56 which provided structural guidelines based on modern fracture mechanics technology. Supplemental Structural Inspection Documents bring failsafe designs into conformity with damage tolerance safety requirements through an enhanced inspection program. Experience has shown that older aircraft designed to the failsafe requirements can be inspected to damage tolerance standards with minimum difficulties.

1.3 PROGRAM GOALS

The FAA's National Aging Aircraft Research Program has a set of interrelated short and long term goals. The short term goal is to define the extent of the aging problem of the current transport fleet. The program will focus on identification and resolution of issues relating to fatigue/multi-site cracking, corrosion, NDI, and human factors. Surveys of the existing systems and procedures used by Government and industry will be made. Current regulations and advisory materials will be reviewed and updated, if necessary. Benefits of the short term program will be in the form of updated documentation for use by government and industry engineering, manufacturing, and maintenance personnel. The products expected from this program are as follows:

- Development of information to update Advisory Circular 43.7 on corrosion control and prevention.
- Development of information to update Advisory Circular 43.3 on nondestructive inspection systems and techniques.
- Development of a human factors handbook covering equipment, work environment, and training needs.
- Development of a damage tolerance handbook for structural design and fabrication.

The long term goal of the program focuses on existing issues applicable to future aircraft. The program will address explaining the failure mechanisms involved in aircraft fatigue and an

evaluation of their detection, predictability, and prevention. New technologies for onboard monitoring, advanced nondestructive inspection, and inspector training will be investigated for possible implementation. Effort will be aimed at developing a structural life management philosophy for new aircraft designs. Benefits of the long term program will be in the form of new technologies and advanced documentation. The products expected from this program are as follows:

- Development of new advanced nondestructive inspection techniques, including the use of robotics.
- Development of new passive systems and procedures for monitoring structural fatigue and corrosion maintenance.
- Development of an advanced damage tolerance handbook covering design, maintenance, and repair practices.

1.4 PROGRAM APPROACH

The National Aging Aircraft Research Program was developed at the FAA Technical Center in concert with an FAA Certification/Flight Standards Management Team, an FAA Oversight Expert Panel, FAA National Resource Specialist, and an Industry Task Force. Other government agencies (including Department of Defense, National Aeronautics and Space Administration), industrial organizations, consultants, contractors, and academic institutions, both here and abroad, have contributed to the plan development.

The FAA is conducting research and development needed to achieve its program objectives. The FAA is involving other government agencies, industry organizations, academic groups, and individuals in the program, as appropriate, and will coordinate these activities at the national and international level. The continuing coordination effort will preclude research duplication and insure the usefulness of program products.

1.5 CRITICAL RESEARCH AREAS

The research program is designed to address the six currently identified critical areas of the aging aircraft problem. (See figure 3.)

FATIGUE/FRACTURE is the research area which deals with crack formation and growth in aircraft structures.

CORROSION is the research area which deals with this damage mechanism and its relationship to fatigue life and damage tolerance.

FLIGHT LOADS is the research area which deals with relating loadings, e.g., pressurization, landing, and gust to fatigue life.

NONDESTRUCTIVE INSPECTION (NDI) is the research area that focuses on finding structural flaws in the aircraft.

HUMAN FACTORS research is concerned with human performance as it impacts on the use of NDI to detect structural flaws.

MAINTENANCE/REPAIR is the research area which is directed at improving the airworthiness of the aircraft structure.

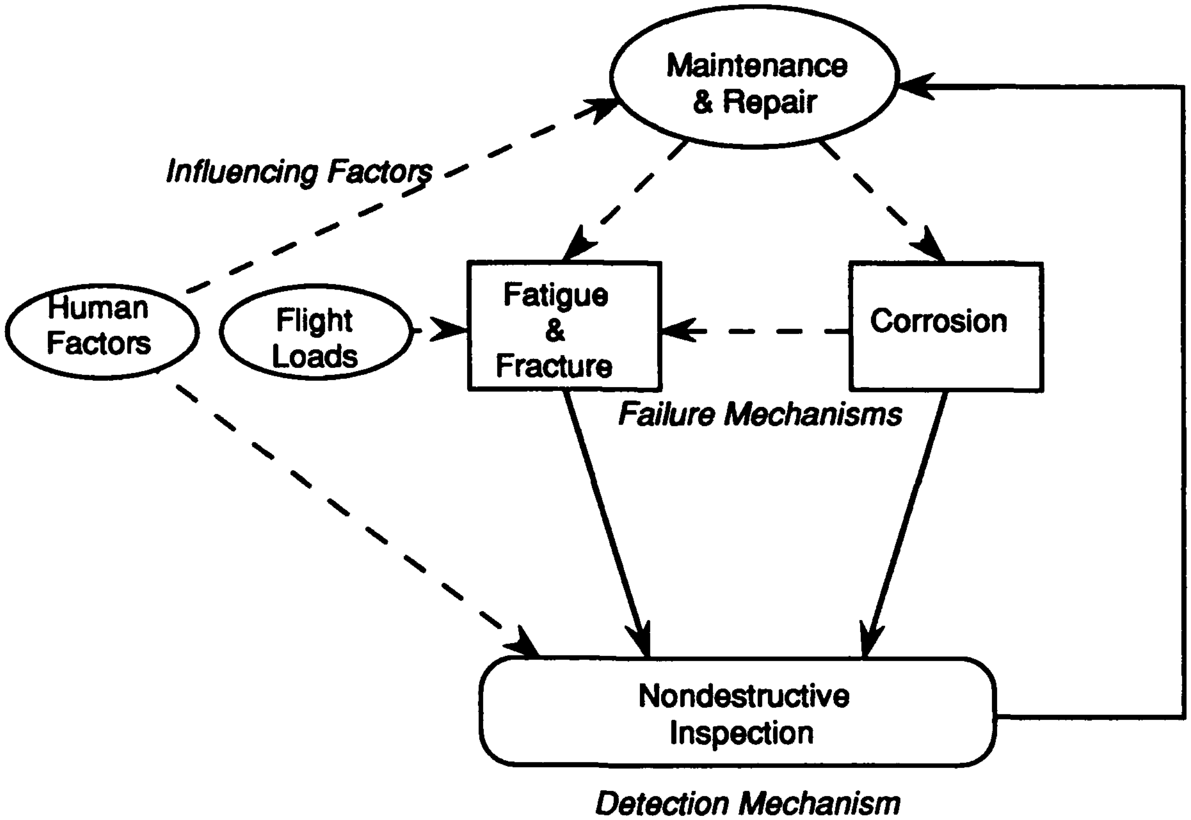


Figure 3. Relationship of program elements. The effects of age are inevitable, but can be slowed. Inspection is the safety net, detecting damage before it becomes critical.

2. FATIGUE & FRACTURE

2.1 INTRODUCTION

The structural fatigue of an aging aircraft is caused by the cyclic loading/unloading due to takeoffs and landings, cabin pressurization, and the in-flight bending and shear loads. Undetected fatigue crack-growth can result in structural damage such as, what is commonly referred to as the multi-site damage (MSD). MSD can consist of very small and difficult-to-detect cracks, emanating from adjacent rivet holes. Typical MSD damage in a test specimen is illustrated in figure 4. The Aloha Airlines incident was caused by the link-up of a series of small cracks emanating from a line of rivet holes, along the lap splice in the crown of the aircraft.

The fatigue life estimation is further complicated by the (not yet fully understood) accelerative effects of corrosion on mechanical fatigue, by the effects of repairs on damage tolerance, and the continued capability to inspect the structure.

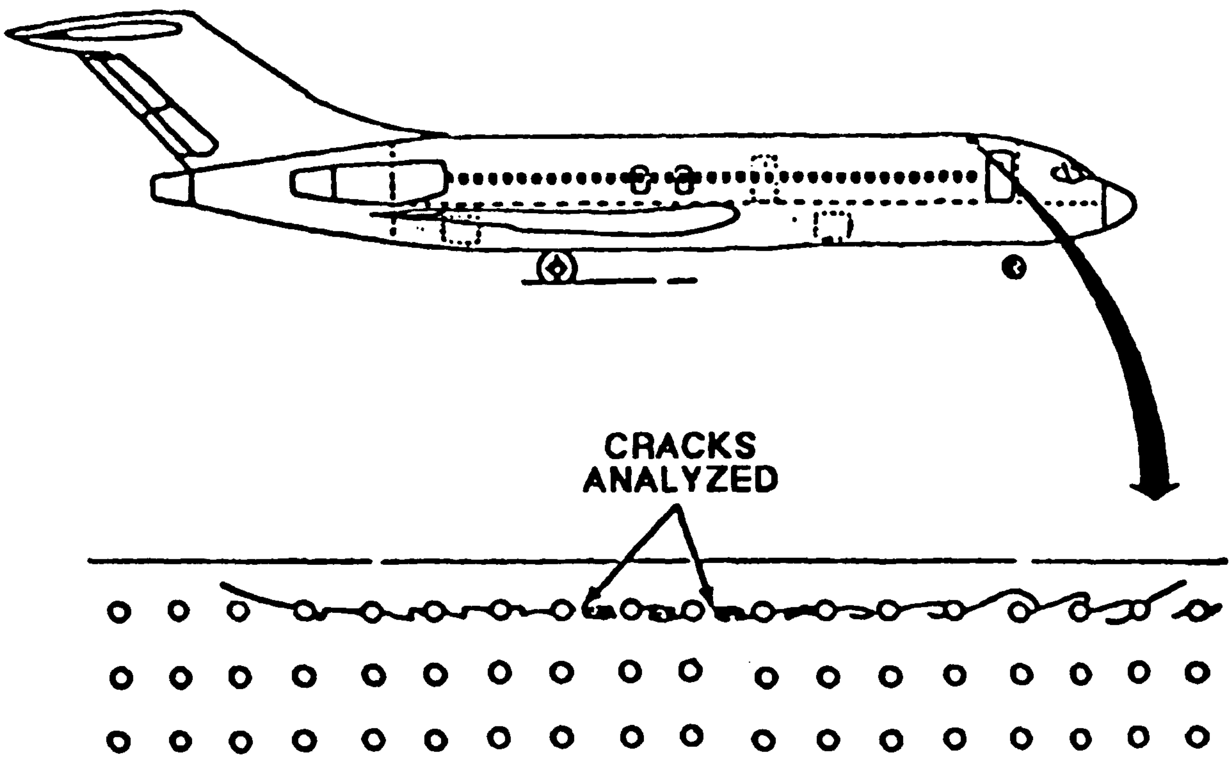


Figure 4. An example of multi-site damage. Cracks which started virtually simultaneously at numerous fasteners on the aircraft linked up.

2.2 TECHNICAL APPROACH

The comprehensive understanding of the fatigue and fracture problems in aging aircraft and an assessment of the adequacy of the existing methodologies to ensure the safe operation of aircraft beyond their initial design life, require the following:

- A review of the original basis of the design of the aircraft.

- A complete understanding of the effects of mechanical and chemical environments, and their interaction on fatigue crack growth and fracture.

Accordingly, the primary approach taken in this research area involves a series of individual investigations concerning the tests, analysis methods, and procedures which are used to verify the safe performance of an aircraft's structure throughout its operational life.

Assessing the structural condition and detecting the structural problems associated with MSD require an understanding of the failure mechanisms and design features that promote MSD. Understanding MSD sufficiently, so as to predict its occurrence while an aircraft is being designed, could eliminate the need for a full-scale fatigue testing later. That same understanding of MSD, coupled with knowledge of the original design basis of today's older aircraft, could reduce the need for testing the current aged fleet.

Numerical modeling and analysis techniques will be developed for MSD test specimen evaluation. These techniques will be applied to actual aged aircraft structures, with MSD, to evaluate their integrity, probability of failure, and residual safe life. The structural integrity model will be validated through a series of special tests. Testing will be done on full-scale, generic test articles fabricated with simulated defects such as fatigue cracks and notches. The tested structural integrity model will then be applied to actual aircraft panels to provide final validation. Data from these proof tests will be used to calibrate the model to predict the susceptibility of aircraft designs to MSD.

Early in FAA's investigation of the aging aircraft problem, the use of proof pressure testing (PPT) was proposed to assure continued safe operation of aging transport aircraft. In PPT, the fuselage is pressurized to a predetermined level and held at that pressure while structural integrity is checked. While the presence of cracks is shown by structural failure, it is shown on the ground and not in the air.

Recent studies by FAA and NASA have determined that destructive PPT is impractical and unacceptable for civil aircraft. The pressure levels required for destructive PPT could introduce unknown and unacceptable damage to the structure from failure modes other than those being tested. Lowering the PPT pressure to preclude other types of damage would require so many repetitive test cycles that the procedure would be uneconomical and impractical. Regardless, the FAA will continue to evaluate all potentially useful destructive and nondestructive methods to test structural integrity.

With regard to structural fatigue and the associated accelerated damage due to the effects of corrosion, investigations will be conducted to quantify the effects of corrosion on crack growth. Material design margins needed to ensure structural integrity in the presence of corrosion will be determined.

A "real time" system of reporting the status and forecasting the needs for managing the aging national transport aircraft fleet will be developed. Individual aircraft listings will include identification, maintenance histories, problems, and corrective actions taken to satisfy Airworthiness Directives, Service Bulletins, and other recommended actions. The system will reference and address all applicable FAA documents used in the certification of the airplane in question, including design, maintenance, and operating rules as well as other relevant FAR materials. The data base provided by this system will be used to develop an understanding, based on field experience, of the following items:

- The synergism between mechanical fatigue and corrosion.
- The development of crack growth rate and crack tip parameter data for tested skin panels.
- The dynamics of MSD linkup.
- The development of inspection criteria based on the probability of detection for individual NDI techniques.

Using the information base generated by this system, the sensitivity of aircraft structures to differing operational environments and system improvements can be assessed. This assessment then provides the basis for a Damage Tolerance Design and Training Manual which the FAA will prepare and distribute to the aviation community.

The FAA also plans to begin an aging aircraft research program for commuter aircraft, even though that segment of the industry has yet to experience the problems which are appearing on large transport aircraft. Commuter aircraft structures and usage are significantly different from those of large transport aircraft, and those differences must be accounted for in the development of a program to maintain and enhance the safety of aging commuter aircraft.

In addition to aircraft design, the FAA will investigate the practices for commuter aircraft inspection, maintenance, and repair to determine their relationship, if any, to structural integrity. These investigations will form the basis for a decision on the need for "damage tolerance" based supplemental structural inspection documents for commuter aircraft.

2.3 PROJECTS

2.3.1 MULTI-SITE DAMAGE

The objectives of this project are to identify the factors that contribute to the development of MSD and to determine the effect that MSD has on current damage tolerance design practices. Mathematical methodologies (closed form solutions, etc.) will be developed to assist in analyzing the likelihood of structural failure, and the residual safe life, of aging aircraft subjected to typical in-service loads. Tests and analytical fracture mechanics models will be developed, employed, and validated to evaluate crack initiation, propagation, and closure effects on MSD and aging metal airplanes damage tolerance.

Schedule:

•	Determination of MSD causative factors	6/91
•	Evaluation of alternative crack measurement techniques	12/91
•	Assessment of the impact of damage tolerance	9/92
•	Effect of bending and shear in MSD	9/92
•	Numerical analysis capability	12/92
•	Crack closure effects	12/92
•	Validation of analytical methodology for MSD damage tolerance evaluation	12/93

2.3.2 Fatigue and Corrosion Dynamics

The objective of this project is to develop a quantitative understanding of the relationship between fatigue and the aggressive chemical environment materials. Efforts will be initiated to develop an understanding of the synergism between mechanical fatigue and corrosion; to develop crack growth rate data and residual strength of fuselage panels with cracks, through tests involving full-scale and skin panel specimens; and to develop inspection interval criteria with an associated probability of detection for each nondestructive inspection technique.

Schedule:

•	Material property characterization utilizing fractography	8/92
•	Inspection interval criteria without corrosion effects	6/93
•	Inspection interval criteria with corrosion effects	6/93

2.3.3 Transport Fleet Assessment

The purpose of this project is to characterize the structural condition of aging airplanes in the U.S.; to correlate histories of their individual maintenance, structural problems; and to identify the corrective actions taken. It will also review and provide data to improve the existing Service Difficulty Reporting (SDR) System.

Schedule:

•	Collect and collate maintenance data vs operational problems	9/91
•	Analyze SDR input to operational data	12/91
•	Identify specific structural problems	12/92
•	Develop fleet data base format/requirements	9/94

2.3.4 Damage Tolerance Handbook

The purpose of this project is to develop a handbook that describes fracture mechanics and damage tolerance principles as they apply to aircraft design and analysis. The handbook will include the identification of methods that can be used to assess the effects of MSD, repairs, and corrosion on the structural integrity of given designs.

Schedule:

- Damage Tolerance Handbook for engineers and maintenance personnel 3/91
- Damage Tolerance Handbook for engineers and maintenance personnel (to include effects of MSD) 6/94

2.3.5 Airworthiness of Commuter Aircraft

The objectives of this project are to assess the effects of aging on the structural integrity of commuter airplanes and to generate data which can be used to determine the need for "damage tolerance" based structural inspection documents (SIDs) for specific aging commuter airplanes.

Schedule:

- Aircraft survey 6/91
- Design features identification 12/91
- Service life reference analysis 6/92
- Damage tolerance criteria development/technique 12/93

3. CORROSION

3.1 INTRODUCTION

Corrosion is a worldwide problem that has been studied and fought since long before the advent of the airplane. There is already an extensive body of knowledge about corrosion, its role in failure mechanics, and its control and prevention. However, as illustrated in figure 5, corrosion problems continue to occur and in the case of aging aircraft they appear to be more prevalent. Incorporating corrosion control considerations and concepts into the design of future aircraft may well be the most effective approach to eliminating this problem in the future.

In aging aircraft, the total structural corrosion problem consists of the following three forms of corrosion:

- Time dependent corrosion, e.g., general corrosion, exfoliation, pitting, and crevice corrosion.
- Time related corrosion, i.e., corrosion fatigue.
- Time independent corrosion, i.e., environmental embrittlement.

Manufacturers and operators address various forms of corrosion through sound design practices and the use of protective coatings. However, corrosion can never be completely prevented. Corrosion control is based on early detection and repair. The economic impact of corrosion prevention and control on both manufacturers and operators is substantial.

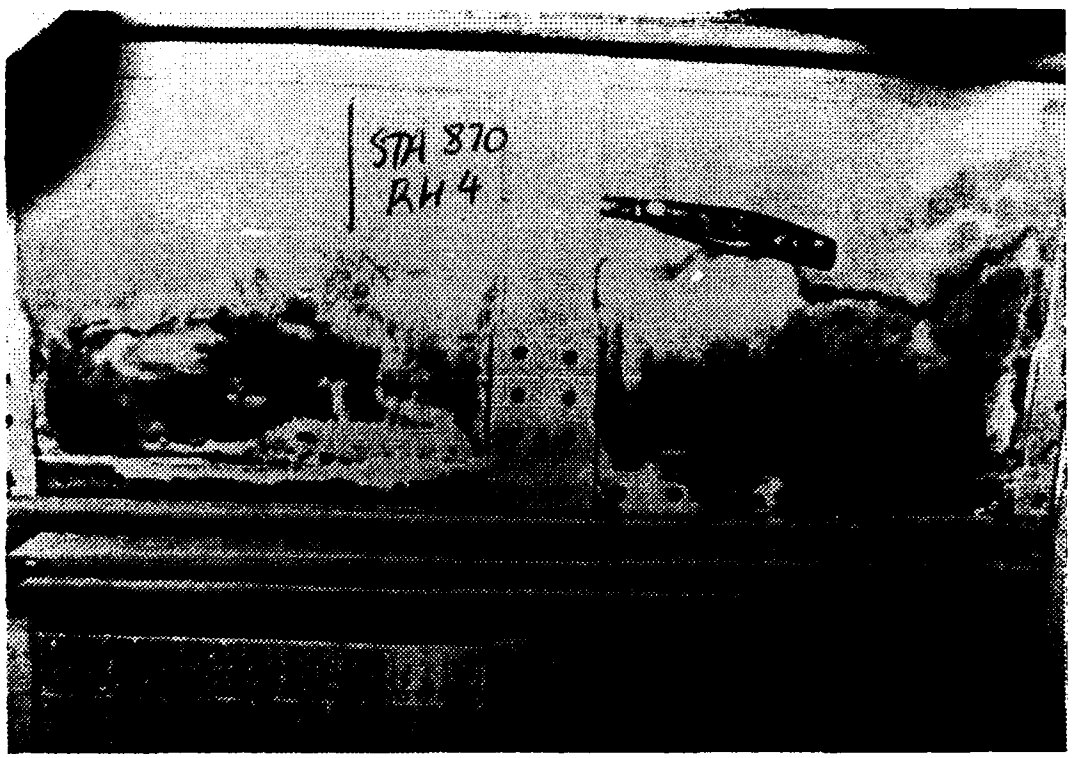


Figure 5. Fuselage corrosion and tear strap disbonding.

3.2 TECHNICAL APPROACH

Building upon the existing knowledge of corrosion of aircraft structures, the following research areas have been identified for inclusion in this program.

The military has a current project on crack arrestment compounds which involves chemical modification of surfaces to prevent and/or arrest corrosion and corrosion fatigue cracking. Of particular interest are those products that displace the corrosive agents and then deposit a corrosion inhibiting barrier film on the surface. These products have been shown to be effective, but application techniques must be developed to facilitate application of the product into corrosion vulnerable areas. The military program will be expanded and adapted for application to civil aircraft.

New self-priming topcoats developed by the military, such as the single coating paint, will be evaluated for civil aircraft applications to determine its advantages with regard to cracking resistance, application costs, environmental impact, adhesion, weight savings, and resistance to degradation from hydraulic fluids commonly used on commercial aircraft.

Evaluation will be made of the use of corrosion monitoring sensors, particularly the thin film corrosion sensors, in areas of the aircraft's structure which are suspected of having high susceptibility to corrosion, e.g., galley, lavatory, cargo hold, sump areas, and highly stressed parts. The requirements on sensors reliability, and of data acquisition, storage, and analysis systems, will be developed.

The effectiveness of current corrosion control technology will be evaluated and graded.

Training materials and courses for FAA inspectors will be upgraded. Training materials will be made available to the private sector.

3.3 PROJECTS

3.3.1 Corrosion Control Products and Procedures

To evaluate research gaps/needs in the existing products as developed by the DOD (paints, cleaners, coatings, preventatives, sealants) and to develop corrective measures, if necessary, for commercial use.

Schedule:

• Select products and identify gap areas	12/90
• Define environmental impact	12/91
• Define cracking resistance	3/91
• Define adhesion characteristics	6/92
• Economic assessment	10/92
• Establish compatibility with commercial products	10/93

3.3.2 Corrosion Control Data Base

This task involves the creation of a corrosion control data base for commercial aircraft. This information will facilitate the detection of corrosion and related problems, provide guidance on cost-effective control, and permit the evaluation of different practices for corrosion maintenance and repair.

Schedule:

• Review and analyze DOD statistics	9/90
• Collate and analyze Service Difficulty Report (SDR) data	3/91
• Review and analyze manufacturers' data	7/91
• Conduct trend analysis	9/91
• Final technical report	12/91

3.3.3 Current Corrosion Control Practices Evaluation

This project will collect and catalog data on the current industrial and DOD procedures for dealing with the corrosion problem. FAA will develop an optimum approach to corrosion control regulatory criteria and thus provide a guidance for industry. It will also define key corrosion-resistant designs, maintenance guidelines, and training guidelines.

Schedule:

• Review industry programs/manuals	2/90
• Analyze DOD corrosion programs	5/90
• Define maintenance guidelines	7/90
• Define key corrosion-resistant designs	10/90
• Support integration of changes to conform with civil usage	11/91

3.3.4 Corrosion Protection Training Materials

Develop phased corrosion training materials, including video presentations for FAA-provided training.

Schedule:

• Collect training information	12/89
• Present prototype to selected FAA maintenance personnel to critique (Phase I)	8/90
• Presentation of 18 seminars to FAA inspectors	9/90-9/91
• Present 5-day course for review with critique (Phase II)	12/91
• Present 2-week course for review with critique (Academy)	9/92
• Convert to video format	12/92
• Provide support to course presentations	thru 96

3.3.5 Corrosion Design/Maintenance Handbook

Develop a combined handbook to provide guidance, technology, requirements for control, detection and prevention of corrosion.

Schedule:

• Collect and review existing maintenance information	12/91
• Collect and review design information	2/91
• Incorporate advanced maintenance data	3/92
• Draft handbook review	7/92
• Publish handbook	3/93

4. FLIGHT LOADS

4.1 INTRODUCTION

In the air and on the ground an aircraft is subjected to critical loads applied to different parts of the structure, from different directions, and in different loading cycles. Figure 6 illustrates the critical loads which can affect the aircraft.

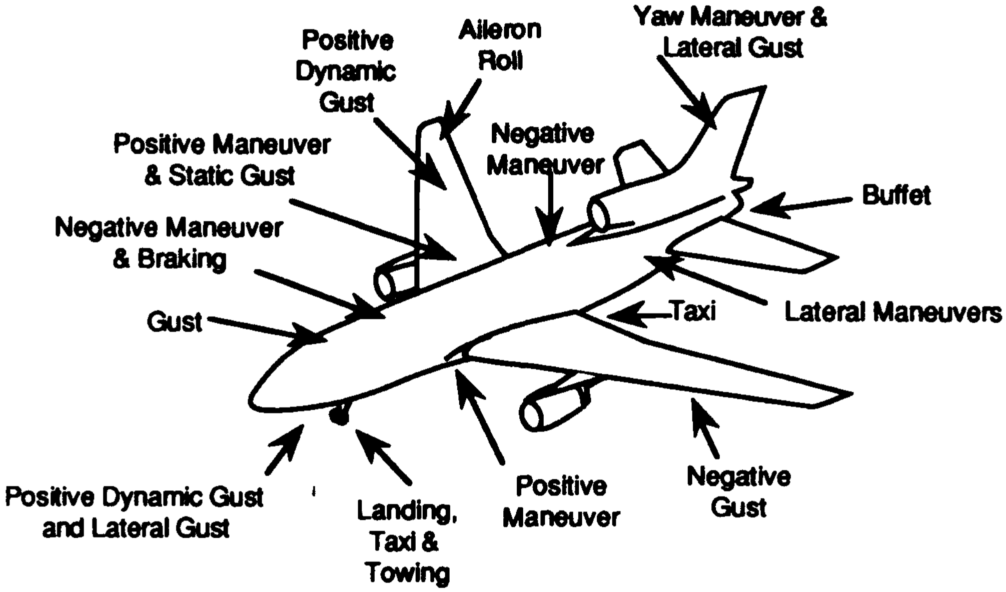


Figure 6. Critical loads on aircraft structure.

Introduction of the hub concept of air travel, more stringent noise abatement flight profiles with rapid climb, descent and turnouts, coupled with deregulation, the increasing demand for air travel, and the lead time needed to acquire new aircraft have all contributed to the situation in which many of today's large commercial transports are being operated beyond their originally intended design life. Consequently, aircraft which continue in service beyond their original design life may be encountering more gusts and maneuvering load cycles than specified in the design, which may contribute to shortening their ultimate fatigue life.

Currently, the only data related to flight loads that are available from the air carriers are the number of flight hours and landings. While these data define the pressurization and landing cycles sustained by the aircraft, they do not represent any other aircraft loading. In the past, flight load data collection programs of U.S. and foreign operators, both civil and military, have not been fully documented, and the data as well as the collection methods were not generally made available to the civil aviation community. For example, the flight loads survey results of the NASA Digital Velocity, G-load, and Height (VGH) Program, covering 5000 hours of fleet service of L-1011, B-727, B-747, and DC-10 aircraft from 1978 to 1982, was unpublished and has only recently been made available. DOT/FAA-CT-89/36, I to IV, "The NASA Digital VGH Program, Exploration of Method and Final Results."

As a rule, load data are not available for smaller commuter and regional air service aircraft. The commuter and regional air carrier fleet consists of approximately 1800 aircraft and is composed of 59 different model types built by 17 different manufacturers. Only a very small

portion of these aircraft is equipped with the onboard avionics needed to record flight loads information.

The FAA will develop a program for monitoring the commuter/regional aircraft flight loads, based on the experience and knowledge gained during the initial operation of the transport aircraft recording program. The program will explore the relationship in loading cycles between small and large aircraft. For example, although the atmospheric gust environment is the same for both the sizes of aircraft, their usage and exposure to gust loadings will be very different.

4.2 TECHNICAL APPROACH

Currently the available data from all sources are not internally consistent, having been collected under different criteria. FAA will assimilate this information to maximize its use and then construct a data collection program that will complement and expand on its usefulness. The appropriate data collection will then be collected on U.S. large transport and commuter aircraft. Following an initial evaluation of the data collection effort for U.S. aircraft, the program can be expanded to include foreign aircraft operating under U.S. registry, as well as U.S. manufactured aircraft operating abroad. The data will be used to determine if the loading criteria, being used for the design and test of both small and large civil aircraft, are representative of realistic operating environments. If necessary, new loading criteria will be developed for future generations of civil aircraft. The basic data can also be used by the participating air carriers to compare the severity of the operational environment by route, to avoid the continuous use of a particular aircraft in severe environments.

A prototype recorder of flight loads data will also be developed for this program. The NASA Digital VGH data indicated that the prior sampling rate may have been too low to capture peak accelerations, leading to an underestimation of the severity of the loadings. The recorder developed for this program will use a higher sampling rate and have significant operational flexibility, and computational capacity, for data acquisition, editing, parameter selection, and capability of being transferred from one model type to another. The recorder will be reprogrammable, will be capable of accepting future enhancements, and will have a nonvolatile memory of at least 300 megabytes for operation without downloading more frequently than the standard "B" level maintenance check which is normally every 8 to 10 weeks.

A microprocessor-based ground station for the processing of flight loads will be developed to provide an analysis of the data and its safe and permanent storage. The data base will be updated with a continuous supply of additional civil aircraft recorder data. The data collected for each aircraft type in the survey will be compiled, analyzed, and presented for each phase of flight (take-off, climb, cruise, etc.) to show the following:

- Distributions of normal and lateral accelerations.
- Altitudes for gusts and maneuvers.
- Gust velocities by altitude.
- Airspeed.
- Weight.
- Flap usage.
- Distributions of take-off and landing velocities.

A successful completion of this research will yield a more representative flight loads data base, which can be used to validate the loading criteria used in aircraft design and test.

4.3 PROJECTS

4.3.1 Collection and Analysis of Transport Flight Loads

To collect and to analyze operational flight loads data, to establish a flight usage data base, and to derive loading spectra for future designs.

Schedule:

• Develop a prototype recorder of flight loads data	6/91
• Develop a ground station for the recording of flight	
• loads data	9/91
• Purchase recorders (6 per year)	91-95
• Data collection	91-95
• Data analysis	92-96
• Load spectra report(s)	96-97

4.3.2 Commuter/Regional Flight Loads

Collect flight loads data from regional/commuter operational aircraft to develop design criteria

Schedule:

• Evaluate fleet to identify needs	8/91
• Select aircraft for instrumentation	12/91
• Design data collection hardware/software	6/92
• Purchase hardware/software system (12)	6/93
• Instrument selected aircraft	9/93
• Data collection/analysis	92/96

5. NONDESTRUCTIVE INSPECTION (NDI)

5.1 INTRODUCTION

The inspection system currently used by U.S. air carrier operators has worked well in the past. However, the increasing size of the fleet of aged aircraft is straining the capacity of the system. Yet, to insure the continued safe operation of the aging aircraft fleet, it is essential that proper NDI equipment and procedures be utilized. There is an accelerating growth of the numbers of reported incidents associated with undetected multi-site damage (MSD), disbonding, and corrosion. This situation has given rise to serious questions about the actual probability of detection (POD) of NDI systems and their reliability in situ.

The reliability of any system falls off dramatically with operator fatigue during repetitive tasks such as examining thousands of identical rivets for MSD-prone areas. Equally disturbing is that a large portion of the discovered cracks were found by chance during undirected inspections. These problems are further complicated by the fact that some aircraft locations are inaccessible to current inspection techniques.

Disbonds in fuselage aluminum sheet lap joints are frequently precursors of serious MSD. A typical skin lap joint with bonding and riveting is shown in figure 7. When the adhesive bonding of the aluminum sheets fails, all of the load is taken by the rivets, and this leads to high stress concentrations at the rivet holes.

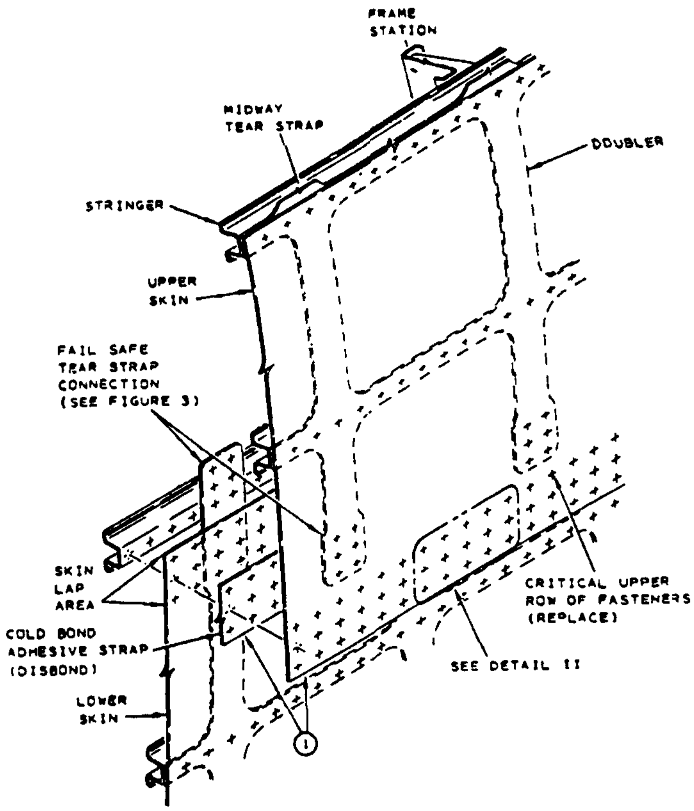


Figure 7. Lap joint inspection specification.

Current bond testers detect disbonds by transmitting ultrasonic pulses through the joined materials, perpendicular to their surface. When there is a void between the bonded parts, the pulse is reflected off the backside of the first part which indicates a single thickness of material, and this is interpreted as a disbond. However, because of the compression provided by the rivets, no void forms when the adhesive fails and the bond tester may falsely indicate a good bond.

In the civil fleet, surface inspections for corrosion are now done visually. Eddy current and ultrasound systems are used to detect subsurface corrosion. These systems actually detect the symptoms of corrosion such as roughened back surfaces; they do not detect corrosion directly. Consequently, false indications and missed detections are common.

Table 1 summarizes the known capabilities of NDI methods and points the way toward identification of deficiencies in those methods. For instance, there are no confirmed techniques for detecting early corrosion or disbonds under compression from mechanical fasteners. There are problems of reliability and practicality associated with the MSD detectors, and there is no NDI technology available to scan large areas. Finally, until advanced automated NDI systems are developed to reduce or eliminate the need for human judgement, the assurance of the integrity of aircraft structures will continue to rely on limited numbers of inspectors, each having his own human limitations .

The NDI training courses offered to the FAA engineers and to the inspectors at the FAA Academy need to be reviewed for possible updating, to include technological advances, such as new the NDI equipment and inspection procedures now finding their way into aircraft shops. Training should be expanded to give FAA and industry inspectors a solid understanding of the physical principles of each NDI technology, to aid them in selecting the method that is most appropriate to a problem. Information on operational experience with new NDI systems should be circulated to all inspectors. FAA Advisory Circulars on NDI must be updated with information on the state-of-the-art NDI equipment and on the new inspection procedures developed for aging aircraft.

An emerging NDI concern is in the area of engine static parts such as turbine cases, diffuser cases, and combustor liners. These items are not now subject to the same level of detailed scheduled inspections as are the rotating engine parts. However, these static parts are subject to fatigue cracking, and there is concern with the ability to find defects in metals that have been repeatedly repaired, in short "in tired metal."

A totally different NDI problem area is the current lack of credible information on equipment performance during field inspections. Hence, there is no information which relates the equipment's detection capability, its application, and the operator's skill level to the POD limits established to ensure structural safety. Moreover, there are no standardized test plans and procedures for validating field inspection performance and comparing it to vendor claims.

Inspection Applications / NDI Method		Fuselage Cracks				Wing Crack		Corrosion					Bond Insp			Engine Comps			Lndng Gear		General Inspections								Characteristics					
		Lap Joints	MSC	Stringers	Frames	Spars	Skins	Initial Onset	Galvanic Lap	Intergranular	Stress Corr	Pitting	Riveted Laps	Bonded only	Bond Strength	Blades	Disks	Cases	Structural	Wheel Insp	Weld Insp	Bolt Holes	Heat Damage	Water Ingress	Metal Sorting	Control Fittings	Honeycomb Dam	Bolt Inspections	Portable	Materials	Thickness Limitations	Speed	Clean Part	Automated
Visual/Borescope		X	X				X					X				X	X	X											G	M	S	G	Y	N
Magnetic Particle												X					X		X		X	X				X		X	F	FM	S, NS	G	Y	N
Eddy Current	(High Freq)	X	X				X				X					X	X			X		X	X		X	X			G	C	S, NS	F	N	N
	(Low Freq)	X	X	X		X			X	X	X	X								X						X	X		G	C	SS	F	N	N
Penetrant											X	X				X	X	X	X	X	X	X						X	G	NP	S	P	Y	N
Radiography	(Gamma X-Ray)			X	X	X										X	X	X	X	X	X	X		X			X	X	F	M	SS	P	N	N
	(Neutron Beam)			?	?	?		?	X	X	X	X				X								X			X		P	M	SS	P	N	Y
Acoustic Emission		?	?	X	X	X					X					X										?	X		F	M	S, NS, SS	F	N	N
Holography																													P	M	S, NS	F	N	N
Ultrasonics	Straight Beam			X	X	X			X	X	X	X	?	X	?				X	X	X					X		X	G	M	NS, SS	F	Y	N
	Angle Beam	X	X	X	X	X	X			X	X	X	?	?	?				X	X	X					X			G	M	NS, SS	F	Y	N
	Surface Wave	?	?				?						?	?	?														G	M	S, NS	F	Y	N
	Resonance												?	?	?														G	M	S, NS	F	N	N
Shearography		?	?	?		?							?	?	?												X		F	M	S, NS	G	N	N
Thermography		?	?	?	?	?			?	?	?	?	?	X	?									X					F	M	S, NS	G	N	N
Barkhausen Noise																			X										F	FM	S, NS	F	N	N
Magneto Optic Eddy Curr		?	?	?	?	?	?		?	?	?																		G	C	S,NS	G	N	N
Computer Aided Tomography																X	X												P	M	S,NS,SS	F	N	Y

Key:

X: Confirmed Application
?: Possible Application
G: Good
F: Fair
P: Poor
M: Most Materials
FM: Ferromagnetic
C: Conducting
NP: Non-Porous
Y: Yes
N: No
S: Surface
NS: Near Surface
SS: Sub-Surface

Table 1: NDI Technology

5.2 TECHNICAL APPROACH

The basic technical approach to NDI R&D starts with a thorough evaluation of the state-of-the-art, proceeds to the development of improvements to current technology and of procedures including training, and ends with the new R&D starts needed to fill the gaps in the existing spectrum of NDI technology and procedures.

In the short term, two surveys of NDI equipment will be made to identify, describe, and assess (1) NDI equipment now used at repair stations and (2) "emerging" NDI equipment which may become available for aircraft inspection. In particular, the existing and newly emerging NDI technologies will be evaluated as to their ability to detect disbonded or weakly bonded structures and surface or hidden area corrosion of aircraft structures. These highly focused areas of investigation will point the way toward the development of prototype systems. The evaluation of future systems will be a continuing effort, and as those system concepts reach maturity, prototypes will be constructed and evaluated.

NDI is currently a labor intensive activity. Laborious, repetitive action is required to inspect large areas such as riveted lap joints. Techniques related to robotics and artificial intelligence will be evaluated to relieve the human performance problems related to repetitive inspection procedures. Additionally, a high priority has been given to automating the signal processing of existing NDI equipment to reduce reliance on human judgement and to provide a permanent record for review if necessary.

Human considerations also point the way toward new research needed to develop robotic devices, which can position and scan NDI probes and transducers over large areas of the aircraft skin. Promising technologies for scanning large areas of an aircraft for defects include acoustic emissions, infrared scanning, and magneto-optic imaging. Some of these technologies are the current state-of-the-art in NDI but remain unproven for practical aircraft inspection applications. As these technologies mature and find practical application, they will be incorporated into a facility for the complete automated structural inspection of an entire aircraft.

An equally important problem is the inspection of currently inaccessible areas. Equipment modifications will be recommended to open those areas to inspection. In parallel, recommendations will be made on future aircraft design criteria to eliminate inaccessible areas.

Existing NDI technology needs to "ask" the structure about its status by means of a diagnostic test. A concept in NDI technology has the structure "tell" about its status. The "smart structure" uses sensors embedded in itself. The technical feasibility of using smart structures for damage detection is presently unknown. Past problems with this approach involved unreliable attachment, calibration, and durability. Other unknowns also exist regarding the compatibility of smart structures to aircraft maintenance procedures and how their output will be collected, reduced, and analyzed. However, the concept of a self-monitoring "autonomous" structure is attractive from the perspectives of providing status reporting and reducing other NDI testing requirements. FAA will pursue R&D for smart structures.

The development of NDI technology for aircraft structures will also be evaluated against the need to inspect static engine parts. New systems to be developed for specific application to the static engine part issue could include eddy current, ultrasonic, acoustic emission, or fiber optic microsensors mounted on or in the engine case to provide diagnostic capability.

Based upon a review of existing NDI regulations and procedures, minimum requirements of equipment capability and operator proficiency will be developed to ensure adequate aircraft inspection. Maintaining adequacy of inspections should be based on the use of standardized testing procedures. Therefore, the FAA will create a centrally located library of realistic specimens, and of the actual aircraft sections, needed to test field inspection equipment and procedures. The test article library also provides the standards against which new equipment and procedures shall be evaluated. Test articles will include various types and sizes of cracks, disbonds, and corrosion.

Training programs for NDI personnel will be updated or newly developed. Training programs will emphasize the use of teaching aids for faster and more efficient student development. Hands-on training with equipment in use in the field will also improve the proficiency of student inspectors. The use of simulators will also be explored for training of the inspectors. A parallel effort will be initiated to quantify the reliability of visual inspections, leading to the development of a new visual inspection training program.

Because of the complexity of the overall nondestructive inspection requirements, the FAA will utilize the abilities of various centers of excellence in support of the different tasks. Specifically the center for Aviation Systems Reliability located at the Iowa State University will be involved in the investigation of new NDI equipment test and evaluation through the prototype stage and the development of curricula for these prototypes. The Development, Demonstration and Training Center located at the Sandia National Laboratory will concentrate on the transfer of prototype systems to industry in an economical and practical approach to operational use. Other centers, currently being formulated will evaluate the application of techniques in use in other regimens, such as for the nuclear power industry, for commercial aviation. NASA will be the prime organization in the application of broad or large area inspection techniques for aircraft use.

5.3 PROJECTS

5.3.1 Current NDI Equipment Survey

Identify, describe, and analyze all NDI equipment currently used at repair stations for the inspection of aircraft airframes and engines.

Schedule

• Identify existing equipment	11/89
• Complete data collection	3/90
• Draft survey	6/90
• Review by FAA	8/90
• Draft final report	2/91

5.3.2 Emerging NDI Equipment Survey

Identify, describe and assess NDI equipment and systems commercially available but, as of yet, not widely used for aircraft inspection.

Schedule

•	Identify emerging equipment	5/90
•	Select equipment to be studied*	7/90
•	Interim report	4/91
•	Evaluate strengths/weaknesses	5/92
•	Draft final report	7/92

*Decision point (equipment selected first will be that which can be developed most rapidly).

5.3.3 Adhesive Disbond and Bond Strength Detection

Evaluate the effectiveness of existing NDI and new technologies (shearography, infrared, ultrasonics, etc.) for their abilities to detect disbonded and weakly bonded structures.

Schedule

•	Technology evaluation of the first system	9/91
•	Lab testing	3/92
•	Design prototype	9/92
•	Prototype evaluation*	3/93
•	Interim report	9/93
•	Report above for two additional systems	3/94,3/95
•	Draft final report	9/95

*Decision point, based on prototype performance

5.3.4 NDI for Corrosion Detection

Develop reliable equipment and techniques to detect surface and hidden area corrosion in aircraft structures.

Schedule

•	Current equipment draft report	2/91
•	Review new technology	9/91
•	Define technology and system specifications	3/92
•	Construct prototype	3/93
•	Evaluate/validate	12/93
•	Aircraft demonstration	6/94

5.3.5 Neutron Radiography Demonstration Program

Demonstrate that neutron radiography can perform broad area corrosion detection on hidden aircraft structure defects.

Schedule

•	Feasibility report based on industry/DOD experience	9/92
•	Small inspection area system design	4/93
•	Prototype fabrication	4/94
•	Prototype evaluated	12/94
•	Large scale system design	6/95
•	Large scale system fabrication	1/96
•	Large scale system demonstration	9/96

5.3.6 Evaluation of Advanced NDI Concepts

Develop and quantitatively evaluate future NDI systems by determining the curves for the probability of detection, false alarm rates, minimum detectable flaw sizes, cost of operation and other performance characteristics.

Schedule

•	Identify promising candidate technologies	9/91
•	Conduct lab evaluations	6/92
•	Incorporate improvements	12/92
•	Fabricate prototype advanced systems	6/93
•	On-aircraft evaluations (first system)	12/93
•	Other system evaluations	through 96

5.3.7 NDI Equipment Research

Improve the signal-to-noise ratio, automate signal interpretation of existing NDI equipment with permament recording for reference to ease reliance upon human judgment.

Schedule

•	Identify NDI equipment to be automated	12/91
•	Prioritize identified equipment	3/92
•	Establish POD's for 4 selected systems	10/93
•	Integrate with robotics	10/94 (first system)
•	Demonstrate system	4/95

5.3.8 NDI of Large Areas

Develop NDI systems capable of inspecting relatively large areas of aircraft structure in order to reduce inspection time and scan repetitions.

Schedule

•	Identify candidate NDI systems	3/91
•	Select systems to be evaluated	9/91*
•	Define broad area specification	3/92
•	Interim report	9/92
•	System evaluations	12/93
•	First system validation	4/94

*Decision point (most promising system)

5.3.9 Automation (Robotics)

Develop portable/transportable robotic device(s) that could automatically position and scan NDI probes and transducers over large areas of flat and curved aircraft structures.

Schedule

• Identify NDI equipment*	6/92
• Build prototype device	4/93
• Integrate with NDI equipment	9/93
• Incorporate automatic signal processing	2/94
• System evaluation (first system)	2/95
• System demonstration (first system)	6/95

*Decision point (most promising system)

5.3.10 An NDI System for Inspecting the Total Aircraft

Establish a facility which would allow complete structural inspections to selectively verify industry's performance of aircraft NDI.

Schedule

• Define system specifications	10/92
• Establish location	7/94
• Aircraft acquisition	7/94
• Equipment acquisition	9/94
• System assembly	3/95
• System validation	9/95
• Initiate operation	1/96

5.3.11 Inaccessible Area NDI

Identify aircraft structures which current NDI equipment cannot inspect owing to lack of accessibility and make recommendations for modifications to future equipment and aircraft to facilitate access to these areas.

Schedule

• Identify inaccessible inspection area problems	2/92
• Identify promising NDI/specifications	4/92
• Design equipment modifications	10/92
• Construct modification prototype	3/93
• Evaluate/validate prototype	10/93
• Draft final technical report	6/94

5.3.12 Smart Structures Concept Investigation

Investigate the feasibility of developing and implanting smart sensing elements in aircraft structures for in situ monitoring of an airframe's structural integrity.

Schedule

• Sensors selection	3/92
• Sensor design and implementation plan	12/92
• Software development	3/92
• Software demonstration	12/93
• Prototype system demonstration (first system)	3/94

5.3.13 Engine NDI Development

Conduct research on new NDI equipment for jet engines.

Schedule

• Identify NDI needs	9/91
• Define NDI equipment modifications	1/92
• Modify equipment	7/92
• On-wing evaluation(s)	2/93
• Draft final report	6/93

5.3.14 Microsensors for the Static Parts of Engines

Develop microsensors which could be retrofitted permanently onto various jet engine static parts to provide in situ structural integrity information.

Schedule

• Sensor selection(s)*	3/92
• Sensor development	12/92
• Software development	3/93
• Sensor performance testing	9/93
• System demonstration (first system)	6/94

* Decision point (most promising)

5.3.15 Minimum NDI Equipment and Proficiency Requirements

Develop minimum equipment and proficiency requirements to insure adequate aircraft inspection at certified repair stations.

Schedule

• Review existing NDI regulations and procedures	3/92
• Develop NDI proficiency minimums	9/92
• Develop minimum equipment requirements	3/94
• Draft Technical report of final recommendation	6/94
• Continue review and update with new equipment	12/96 and on

5.3.16 Sample Defect Library

Assemble a comprehensive library of specimens and samples comprising the major types of damage encountered in aging aircraft for use in determining NDI equipment performance characteristics/specifications of inspection procedures.

Schedule

• Identify sample requirements (types of defects needed)	11/90
• Acquire and/or manufacture defect samples	9/92
• Complete defect characterizations	6/93
• Establish library controls	9/93
• Periodic NDI system validations	continuous thru 95

5.3.17 NDI Training

Develop and update training courses, Advisory Circulars, handbooks, and training aids to teach FAA and industry NDI personnel the various NDI technologies.

Schedule

• Review existing training	9/91
• Define course outline	3/92
• Develop training aids	6/92
• Develop course materials	9/92
• Prepare ACs and handbooks	12/92
• Course prototype	3/93
• Demonstration course	6/93
• Initiate repetitive course	1/94

5.3.18 Visual Inspection

Quantify the reliability of visual inspection procedures, establish limits covering visual acuity, and develop an adequate visual inspection training program.

Schedule

• Assess visual reliability	12/91
• Survey visual enhancement equipment	1/92
• Establish visual limits and requirements	3/92
• Define a visual training program	9/92
• Develop visual training program	8/93
• Test training program	2/94

6. HUMAN FACTORS

6.1 INTRODUCTION

The maintenance and inspection personnel, who are responsible for aircraft airworthiness, are the first line of defense against the age-related structural integrity problems. The performance of these workers is directly related to the design of their tasks, the training given to them, the tools they work with, and the nature of their work environment. Figure 8 illustrates some of the difficulties inspectors encounter, i.e., noise, uncomfortable body position, and the need for safety harnessing. In order to maximize safety, inspectors and mechanics should work in a carefully structured environment with equipment and procedures designed to minimize the potential for human error. This segment of the aging aircraft program addresses the research and development needed to improve the performance of maintenance and inspection personnel.

The human factors element of the National Aging Aircraft Research Program will be coordinated with the FAA's National Plan For Aviation Human Factors, which is expected to be released in 1991. This national plan will coordinate the FAA's efforts with those of other Federal agencies, academia, and industry.

Figure 8. Maintenance technician inspecting upper lobe of aircraft fuselage with eddy current probe.

6.2 TECHNICAL APPROACH

The technical approach to the human factors R&D task starts with analysis of maintenance and inspection tasks, proceeds to an evaluation of existing practices and procedures, and ends with a set of new R&D starts needed to fill the identified gaps.

The goal of human factors R&D for maintenance and inspection is to minimize human errors made during the performance of these tasks. Thus, it is necessary to first define and classify human error so that error reduction can be measured. Human error is related to a number of conditions such as skill, attitude, and work environment. Aircraft inspection frequently involves a speed/accuracy trade-off which can increase job stress and lead to reduced performance. The job stress/performance level relationship will be determined as a function of work load. A detailed work task analysis will be made to develop descriptions of the activities of maintenance and inspection personnel. Task analysis will be used to define errors by task element and the conditions which are likely to contribute to those errors.

Existing communication and information transfer techniques will be studied. Standardized and simplified vocabularies which can expedite communication will be studied to determine their role in error reduction. Evaluations will be made of programmed learning systems, which provide instruction to the technician on likely fault sources, repair procedures, required skill types and levels, and repair part specifications. These systems may use interactive graphic displays. Current learning systems are based on the use of work cards, manuals, and other technical documents. However, the learning process has become increasingly inefficient as the volume of technical materials has grown and the environment of information transfer has become broader and more complex.

Research will also focus on training methods and technology. Currently, a large portion of the training of aircraft mechanics and inspectors involves on-the-job training (OJT). While there is nothing inherently wrong with OJT, its quality is difficult to control, and the time it takes to distribute it in the field can be lengthy. The methods and technologies which have found acceptance in other industries, such as computer based instruction and intelligent tutoring systems, could enhance the training of airline mechanics and inspectors.

Research on human factors as they pertain to NDI equipment design will also be performed. It is critical that NDI equipment be designed to recognize human capabilities and limitations. Both currently available and proposed equipment will be evaluated for "human engineering" problems and "fixes". Design guidelines will also be developed.

An analysis will be made of existing and planned systems for onboard diagnosis of civil aircraft structures. Many aircraft manufacturers are proposing these systems to reduce maintenance burden. It is possible that some of the status reporting included in those systems could be of value to the maintenance and inspection process.

In addition to specific outputs of this program, such as the training materials and task analysis, a summary Inspection and Maintenance Handbook will be developed and distributed throughout the FAA and the aviation community.

6.3 PROJECTS

6.3.1 Task Analysis

Study, observation, and identification of component and sub-tasks of the aircraft inspection and maintenance process which are sensitive and likely to contribute to error.

Schedule

•	High level system description	12/89
•	Functional level system analysis	1/90
•	Task analysis	5/90
•	Final report	10/90
•	Contract award (new task)	10/90
•	Collect data Phase II	6/91
•	Final report	11/91

6.3.2 Analysis and Classification of Human Error

Descriptions of errors and error patterns which can be linked to identifiable contributing activities.

Schedules

•	Data acquisition	8/90
•	Error analysis report	6/91

6.3.3 Job/Task Work Environment Analysis

Evaluation of related factors influencing work site performance, such as access, lighting, noise, and ambient temperature effects.

Schedule

•	Define environment	9/90
•	Evaluate factors	12/91
•	Report on work environment	6/92
•	Report on time pressure assessment	9/92

6.3.4 Information Exchange and Communications

To facilitate the access to information required to perform an aircraft inspection and/or maintenance task.

Schedule

•	System evaluation	12/91
•	Data collection	12/92
•	Analysis	9/93
•	Recommendations concerning communication	9/93

6.3.5 Job Performance Aids

Provide instructions to the technician on the likely sources of faults, details on repair procedures including graphical displays, personnel specialties required to make repairs, and repair part numbers.

Schedule

•	Identify devices	6/91
•	Evaluation	12/92
•	Analysis	5/93

6.3.6 Training Research

Development of a prototype computer based instruction (CBI)/intelligent tutoring systems (ITS) which can be used by a typical air carrier for the performance of a maintenance task.

Schedule

•	Review current air carrier training	8/90
•	Prototype CBI/ITS software development	2/91
•	Completion of turnkey ITS	12/91
•	Evaluation and modification of ITS	12/93
•	Validation of ITS	12/94

6.3.7 Equipment Design Research

NDI equipment design research on human capabilities and limitations.

Schedule

•	Survey maintenance equipment	6/91
•	Evaluate equipment	12/92
•	Report on equipment design	6/93

6.3.8 Handbook Development

Incorporation of information from tasks HF1 through HF7 to form a unifying vehicle for human factors information gained in other tasks.

Schedule

•	First draft of handbook	10/90
•	Revision/update #1	10/91
•	Revision/update #2	10/92
•	Revision/update #3	10/93

7. MAINTENANCE AND REPAIRS

7.1 INTRODUCTION

Proper maintenance is the foundations of any program to insure the continuing airworthiness and operational safety of an aircraft, and this is particularly true within the context of the aging civil fleet. However, maintenance involves down time and takes an aircraft out of productive service. There have been concerns raised that the pressures for faster turnaround times, due to the growth of demand for air transportation, could adversely impact maintenance operations.

Another concern is that repairs may lead to additional damage to the structure if the aircraft's original design philosophy or the manufacturers repair guidelines are not strictly followed. A typical external repair of a fuselage skin panel is shown in figure 9. A poor repair will not uniformly distribute the forces across the entire patch and this may lead to localized failure and additional damage.

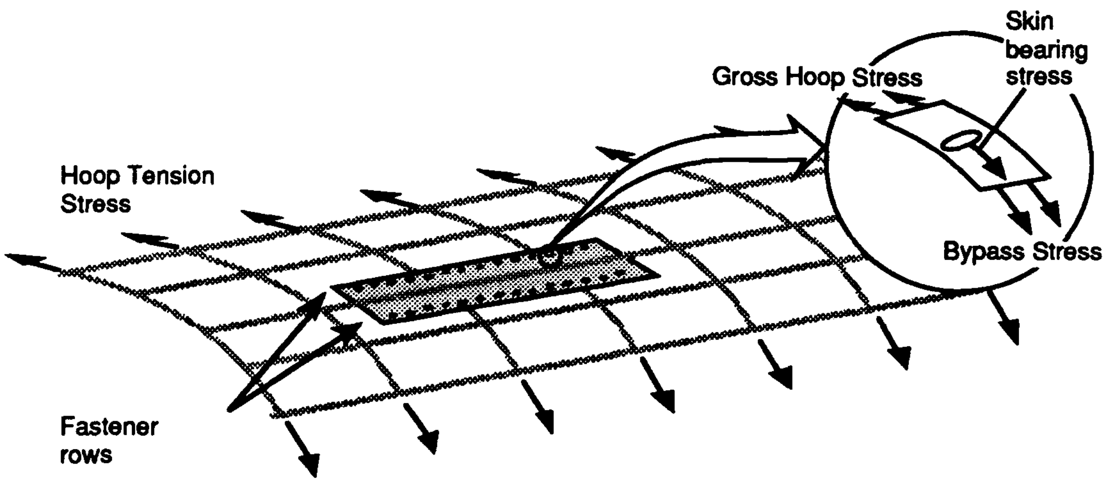


Figure 9. External repair to fuselage skin. Improper repairs increase stress concentration factors, reducing fatigue life.

In general, repair of an airframe component can degrade its fatigue life if the original design philosophy and details are ignored. Historically, engineering evaluations of structural repairs have been based on equalling or exceeding the static strength of the original design with no consideration given to fatigue life. This philosophy can easily lead to static strength overdesign accompanied by reduced fatigue life, as compared to the original structure. In addition to degrading fatigue life, the repair itself may reduce the inspectability of the structure.

Current regulations require that repair or modification of commercial transport category airplanes must be evaluated for damage tolerance if (1) the aircraft was certified as per the damage tolerance regulations of FAR 25.571 or (2) if the aircraft has a mandated Supplemental Structural Inspection Document (SSID). The rationale for this requirement is that the in-service structural safety of these aircraft is being managed by an inspection program which is based upon a damage tolerance design philosophy.

The original manufacturer of the aircraft is normally the most qualified evaluator of damage tolerance. The manufacturer is most likely to possess all of the data on structural loads and stress needed for an evaluation. However, repair stations, small modification companies, operators, and designated engineering representatives, have been known to modify or repair aircraft structures without the benefit of the design information. This problem can be alleviated by providing conservative simplified methods for performing crack growth and residual strength analysis to those who repair and modify aircraft. Standardized repair practices and improved dissemination of maintenance and repair information to the aviation community must also be developed.

Engine maintenance is frequently performed for an operator by other carriers, under contract, or by independent repair stations. Therefore, variations in engine maintenance practices may exist. The effect of repair practice variability on engine failure rates, operational difficulties, and the life expectancy of the static parts of an engine is unknown and must be determined. Reliable on-wing inspection techniques must be developed for gas turbine engine static parts. The NDI technology now used to detect intergranular corrosion and precipitation hardening of the super alloys used to fabricate engine cases also needs to be reevaluated in light of the aging of the civil fleet.

7.2 TECHNICAL APPROACH

The technical approach to the R&D effort in maintenance is based upon a thorough survey and evaluation of the existing state-of-the-art of applicable techniques and the dissemination of information about them. Projects will be developed to fill any identified gaps and to answer specific questions which have already been raised by the FAA and industry.

A survey will be made of existing data bases to determine if there is any correlation between repair practices, service utilization histories, and subsequent service difficulties.

The performance of commonly used repair patch configurations will be analyzed. Fatigue load criteria for fuselage stress levels will be developed for testing and analyzing repair patches. Tests will be conducted to assess the fatigue resistance and structural integrity of common repair configurations. Analytic techniques will be developed to predict the performance of repairs and they will be validated by tests of actual patches.

Evaluations will be made of the original safe life designs of commuter aircraft to determine the applicability of present damage tolerance inspection, repair, and maintenance procedures. Additionally, an evaluation will be made of the maintenance procedures actually used versus the procedure recommended by the manufacturer. This evaluation will also address third party maintenance providers and Department of Defense practices. Tests will be conducted to verify relations developed between maintenance procedures and structural integrity from a damage tolerance point of view.

Analytical procedures will be developed, and validated, to predict the load transfer characteristics of composite material patches on metal aircraft skins. A composite patch material data base will then be developed to provide field guidance in the selection of bonding materials and methods, application techniques, and crack inspections.

Engine maintenance procedures will be surveyed and documented. Airline and repair station maintenance procedures will be compared to determine if variability exists between them. Existing data bases will be surveyed to collect information on in-flight shutdowns and removals, and engine component failures. Operational problems will be correlated with

maintenance procedures to determine if failure rates reflect the variability in maintenance procedures. The need to investigate the validity for standardized maintenance procedures will be documented if the analysis indicates that the variability between procedures is reflected in the failure rates. On-wing inspection procedures and equipment requirements will be developed for engine static parts.

A maintenance and repair information system will be developed to facilitate the rapid dissemination of detailed information to the aviation community. This research will focus on developing a data format, content, and user/system interface which will be acceptable to all sectors of the aviation community involved in aircraft maintenance and repair.

7.3 PROJECTS

7.3.1 Effects of Airframe Repairs on Structural Integrity

In this project, researchers will evaluate repair data bases and ascertain the impact on damage tolerance and inspectability that various types of repairs impose on the aircraft structure. Also modifications will be investigated with respect to degrading damage tolerance and increasing multi-site damage (MSD). Current analytical techniques will be evaluated/developed and verified for utilization by repair stations.

Schedule:

• Repair data base assessment	2/91
• Review current civil and DOD repair technology	9/91
• Evaluate current analytical techniques	12/91
• Evaluate STC-type modifications on damage tolerance/MSD	6/92
• Validate analytical techniques	6/93

7.3.2 Effect of Maintenance and Structural Integrity

The focus of this project is on characterization of the effects that various maintenance practices such as paint stripping, shot-peening, cold working of fastener holes, and cleaning/polishing techniques have on the structural integrity of in-service civil airplanes of the fixed-wing type.

Schedule:

• Maintenance practices identification	9/91
• Small scale testing	3/92
• Analysis of test results	9/92
• Final technical report	3/93

7.3.3 Composite Repairs of Metallic Structures

This project is designed to evaluate the effects that the bonded patches of composite materials have on the damage tolerance characteristics of metal aircraft structures. Stress levels, fatigue life material properties, patch configurations, bonding methods/application techniques, and environmental factors will be included in the evaluation. Numerical and analytical procedures to evaluate the aforementioned factors will be developed and verified.

Schedule:

• Identify actual and potential repairs	10/91
• Establish load transfer characteristic	3/92
• Test analytical procedures	9/92
• Validate methodology	9/93
• Publish final report	2/94

7.3.4 Documentation of Conditions of Static Components of Engines

Document the reliability and maintainability of inspection and measurement techniques used to inspect aircraft gas turbine engines. Engine and engine component failures and engine reliability modifications will be reviewed, and on-wing NDI procedures will be developed to determine the structural integrity of engine static components.

Schedule:

• Define maintenance/inspection procedures for engine static components	8/90
• Document static component related failures/removals scheduled	10/90
• Develop NDI procedure for static components	1/91
• Validate inspection procedures	3/91
• Technical report	4/91
• Option to repeat above for other engines	4/92

7.3.5 Aging Engine Analysis

This project is designed to define the characteristics of the life limits; determine the factors that affect the life cycle; provide certification support data on the life cycle; and identify repair limitations/inspection intervals for in-service turbine engine static parts.

Schedule:

• Document current repair/replacement cycles	7/91
• Identify critical life cycle factors	12/91
• Validate life cycle criticality	3/93
• Develop inspection/repair interval requirements	9/93

7.3.6 Engine Maintenance Procedures

This project will document the variability in the repairs of aging engine static parts by different maintenance organizations; evaluate the impact of this variability on life expectancy of the part; and determine if such variability contributes to failure or operational difficulty.

Schedule:

• Survey maintenance procedures	7/91
• Variability documentation	8/91
• Impact data collection	10/91
• Impact analysis	2/92
• Technical report	6/92

7.3.7 Aircraft Repair/Maintenance Data Management

The focus of this project will be on improving the technical performance by optimizing the content, availability, usability, exchange, and management of repair/maintenance technical information at all levels of the aviation industry.

Schedule:

• Communication/information audit	9/91
• Demonstration plan	10/91
• Prototype intelligent information development	2/92
• Formulation of specification	8/92
• ISN concept demonstration	2/93
• Fleet data base format and requirements	9/93
• Data base/system integration	6/93
• Network interface specification	12/93
• Analysis system specification	9/94
• Intelligent intermediary specification	9/94

7.3.8 Airframe Maintenance and Repair Handbook

This project will produce a handbook which will document appropriate airframe repair and maintenance practices and equipment for aging aircraft for FAA and repair station personnel.

Schedule:

• Identify manufacturer practices	9/91
• Identify airline/User practices	4/92
• Identify repair station practices	7/92
• Identify DOD technology	11/92
• Develop appropriate analytical tools/techniques	9/93
• Develop handbook	9/93

8. PROGRAM INTEGRATION

8.1 INTRODUCTION

The National Aging Aircraft Research Program addresses the issues necessary to satisfy both the FAA as well as industry needs. The program consists of six major R&D areas and each consists of a number of specific projects. To ensure proper response to FAA and industry needs, a program integration function has been established to:

- Establish, schedule, fund, and monitor projects with other elements of government, industry, academia, and research institutions. Project vehicles may include contracts, interagency agreements, memoranda of understanding, etc.
- Correlate and coordinate interrelated projects and monitor their progress and products.
- Conduct workshops and conferences where relevant issues can be discussed and resolved.
- Disseminate information to the FAA and industry management, oversight, and advisory groups to inform them of status and progress.
- Modify program direction to reflect interim results and new requirements.

The R&D areas defined in this plan have some degree of technical commonality and may even share similar data bases. Figure 10 illustrates the cross-correlation of the six major R&D areas. The program integration function will establish and maintain the inter-project communication and technical exchange needed to insure that each project is an integral part of the national goal of insuring continued airworthiness of the aging fleet.

R&D area interface management will be an ongoing effort and will address the following issues:

- Coordinate all projects having technical interfaces or interdependent contributions to specific airworthiness issues.
- Review the overall program progress relative to its stated goals.
- Revise the program to reflect new issues, interim results, changed priorities, and updated schedules.
- Inform the management and the technical oversight and advisory committees of the progress, and disseminate products to the proper recipients.

	Fracture & Fatigue	Nondestructive Inspection	Human Factors	Repairs & Maintenance	Corrosion	Flight Loads
Fracture & Fatigue		X		X	X	X
Nondestructive Inspection	X		X	X	X	
Human Factors		X		X	X	
Repairs & Maintenance	X	X	X		X	X
Corrosion	X	X	X	X		
Flight Loads	X			X		

Figure 10. Cross-Correlation of Major R&D Areas.

8.2 PROGRAM MANAGEMENT AND RESPONSIBILITY

The FAA Technical Center's Engineering, Research, and Development Service, Aviation Safety Division, is responsible for the overall conduct and management of this program. With direction from the FAA Headquarters Directorate for Systems Development, the Aviation Safety Division prepares and updates the National Aging Aircraft Research Plan and manages the research projects to insure that program goals are being met. Other government agencies and industry working groups provide input to the plan and monitor its progress in meeting those national goals.

8.3 SCHEDULE

The overall schedule of the aging aircraft program is shown in figure 11.

8.4 FACILITIES

It is the general philosophy of the FAA to use existing facilities for its own research. However, the FAA does establish facilities under its own control if new capabilities are needed. Due to the critical need for aging aircraft research and the unique problems of civil aircraft, reliance on existing Department of Defense, academic, or foreign laboratories is not feasible. This

program will make use of the Center for Aviation Systems Reliability (CASR) and the Development, Demonstration and Training Center (DDTC).

CASR is an academic consortium led by Iowa State University and it has received special appropriations for Fiscal Year 1990 and 1991. The primary contribution of CASR will be in the areas of NDI research, human factors, and communications/information exchange.

The DDTC is a consortium under the Sandia National Laboratory to facilitate the practical introduction of NDI prototype equipment and training into operational use.

Additional Centers will be established and supported to capitalize on the knowledge and techniques from other industries such as nuclear power for aircraft use.

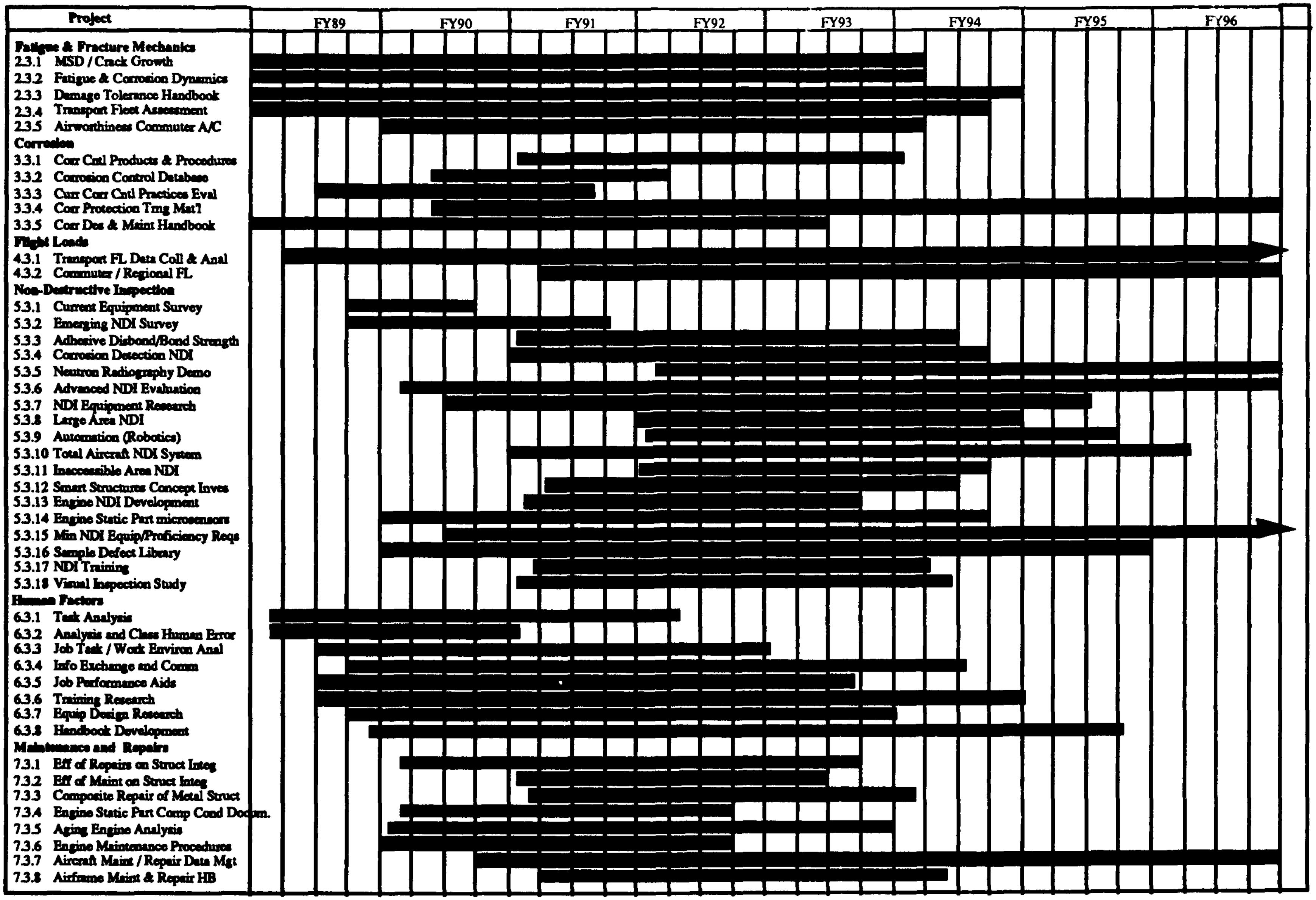


Figure 11. Schedule

APPENDIX A - APPLICABLE DOCUMENTS

Federal Aviation Regulations (FAR)		Cognizant FAA Office	Effectivity Date
Part 21	Certification Procedures for Products and Parts	AIR-200	07/24/89
Part 23	Airworthiness Standards: Normal, Utility, and Acrobatic Category	ACE-100	08/18/90
Part 25	Airworthiness Standards: Transport Category Airplanes	ADM-100	07/24/89
Part 33	Airworthiness Standards: Aircraft Engines	ANE-100	10/03/88
Part 39	Airworthiness Directives	AIR-100	05/19/74
Part 43	Maintenance, Preventive Maintenance, Rebuilding, and Alterations	AFS-300	12/13/88
Part 65	Certification: Airmen Other Than Flight Crewmembers	AFS-200	04/11/89
Part 91	General Operating and Flight Rules	AFS-200	07/23/89
Part 121	Certifications and Operations: Domestic, Flag, and Supplemental Air Carriers and Commercial Operators of Large Aircraft	AFS-200	07/24/89
Part 135	Air Taxi Operator and Commercial Operators	AFS-200	06/02/89
Part 145	Repair Stations	AFS-300	01/23/89
Part 147	Aviation Maintenance Technician Schools	AFS-300	06/26/78
AC 20-77	Use of Manufacturer's Maintenance Manuals	AFS-310	03/22/72
AC 20-95	Fatigue Evaluationof Rotorcraft Structure	ASW-100	05/18/76
AC 20-106	Aircraft Inspection for the General Aviation Aircraft Owner	AFS-340	04/78
AC 20-107A	Composite Aircraft Structure	ASW-130	04/23/84

Federal Aviation Regulations (FAR)		Cognizant FAA Office	Effectivity Date
AC 20-108	Report No. AFS-120-73-2, Fatigue Evaluation of Wing and Associated Structure on Small Airplanes	AFS-120	08/17/78
AC 23-3	Structural Substantiation of Secondary Structures	ACE-111	09/05/85
AC 25.571-1A	Damage-Tolerance and Evaluation of Structure	ANM-110	03/05/86
AC 39-6M	Summary of Airworthiness Directives	AVN-113	04/06/88
AC 39-7B	Airworthiness Directives for General Aviation Aircraft	AFS-340	04/08/87
AC 43.9-1E	Instructions for Completion of FAA Form 337 (OMB No. 2120-0020). Major Repair and Alteration (Airframe, Powerplants, Propeller, or Appliance)	AFS-340	05/21/87
AC 43.13-1A	Acceptable Methods, Techniques and Practices-Aircraft Inspection and Repair	AVN-110	04/17/72
AC 43.13-2A	Acceptable Methods, Techniques and Practices-Aircraft Alterations	AFS-340	06/09/77
AC 43-3	Nondestructive Testing in Aircraft	AFS-330	06/09/77
AC 43-4	Corrosion Control for Aircraft	AFS-330	05/11/73
AC 43-7	Ultrasonic Testing for Aircraft	AFS-310	1974
AC 43-9B	Maintenance Records for General Aviation Aircraft	AFS-310	01/09/84
AC 43-12A	Preventative Maintenance	AFS-310	10/28/83
AC 65-2D	Airframe and Powerplants Mechanics Certification Guide	ASF-340	01/30/76
AC 65-9A	Airframe and Powerplants Mechanics -General Handbook	AVN-130	04/12/76
AC 65-15A	Airframe and Powerplants Mechanics Airframe Handbook	AVN-130	04/12/76
AC91-56	Supplemental Structural Inspection for Large Transport Category Airplanes	AWS-120	05/06/81

Federal Aviation Regulations (FAR)		Cognizant FAA Office	Effectivity Date
AC91-60	Continued Airworthiness of Older Airplanes	AFS-310	06/13/83
AC 120-16C	Continuous Airworthiness Maintenance Programs	AFS-350	08/08/80
AC 145-3	Guide for Developing and Evaluating Repair Station Inspection Procedure Manuals, with change	AFS-310	02/10/82
AC25.1529-1	Instructions for Continued Airworthiness (Draft)	ANM-110	01/13/89

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